2023 NDIA MICHIGAN CHAPTER
GROUND VEHICLE SYSTEMS ENGINEERING
AND TECHNOLOGY SYMPOSIUM
MODELING SIMULATION AND SOFTWARE (MS2) TECHNICAL SESSION
AUGUST 15-17, 2023 - NOVI, MICHIGAN

A VIRTUAL SPECTATOR SYSTEM FOR VIRTUAL EXPERIMENTATION IN MULTI-USER VIDEO GAME ENVIRONMENTS

Wing-Yue Geoffrey Louie, PhD[1], Motaz AbuHijleh[1], Sean Dallas[1], Mark Brudnak, PhD[2], Gregory Pappas[2]

[1]Department of Electrical and Computer Engineering, Oakland University, Rochester, MI
[2]Ground Vehicle Systems Center, Warren, MI

ABSTRACT

Virtual experiments are used by the US Army to evaluate and obtain soldier feedback on new technologies. These evaluations are currently limited to obtaining soldier self-reports to determine the effectiveness of technologies and attain feedback for future improvements. Current virtual experiments are unable to accommodate external observers to spectate and evaluate soldier interactions with technologies due to difficulties in spectating the fast-paced multi-user interactions occurring during virtual experiments conducted by the US Army. In this paper, we present our research on identifying US Army requirements for a spectator interface and the design as well as development of a spectator interface system to address these challenges in virtual experimentation. A case study focusing on virtual experimentation for a human-robot teaming security scenario is then presented to demonstrate the usage and utility of the developed virtual spectator system.

Citation: W.-Y. G. Louie, M. AbuHijleh, S. Dallas, M. Brudnak, and G. Pappas, “A Virtual Spectator System for Virtual Experimentation in Multi-User Video Game Environments,” In *Proceedings of the Ground Vehicle Systems Engineering and Technology Symposium* (GVSETS), NDIA, Novi, MI, Aug. 15-17, 2023.

1. INTRODUCTION

Multi-user video game environments enable the Army to perform rapid virtual experimentation with soldiers to obtain their feedback on user experiences towards new technologies [1]. During these virtual experiments, teams of soldiers come together virtually with a range of simulation hardware which allows them to interact with new technology concepts. The hardware often ranges from having each soldier use a computer with a keyboard and mouse to fully immersive simulated environments (e.g., CAVE, HMDs, or physically simulated equipment). Soldiers then interact with each other through a networked connection providing access to the video game environment. By introducing new technologies in virtual experiments, soldiers

DISTRIBUTION A. Approved for public release; distribution unlimited. OPSEC#7301

can then provide feedback in areas such as vehicle crew configuration, formations, vehicle capabilities, unmanned aerial vehicles, aided target recognition, and networked capabilities [1],[2].

Feedback during virtual experimentation primarily focuses on capturing user self-reported experiences towards virtually prototyped technologies because these environments have been primarily designed for users to interact within them. Although user self-reported experiences are important, direct observation of user behaviors should be utilized to complement self-reports because self-reported responses are not always congruent with users' actual behaviors with technology and introduces individual biases [4].

However, currently it is difficult for an observer to spectate users in video game environments because they have been designed with esports in mind and their primary motivations have been towards spectator entertainment [3]. This does not align with the goals of virtual experimentation as spectators can only either follow a single user from a first-person perspective, control a spectator camera to freely roam within the video game environment, or utilize a customized interface designed for a single game. Hence, current spectating interfaces are not suitable for virtual experimentation because they do not consider the needs of an external observer such as spectating at different levels of organization; interpreting large quantities of data with complex interactions between users; and monitoring the intent, state, and actions of a user or a group of users.

There is presently a need for leadership, engineers, and/or researchers to observe virtual experiments to evaluate the effect introducing new technologies has on soldier behaviors. To spectate soldiers effectively and efficiently within these environments, challenges must be addressed in relation to spectating at different levels of organization, spectating a fast-paced multi-user interaction environment, and lack of transparency in soldier actions. There is currently an open opportunity in virtual experimentation research for improving the spectator experience.

The overall goal of this research was to address this gap in virtual experimentations by enabling stakeholders to effectively spectate a virtual experiment within a multi-user gaming environment to gather observations on solider behaviors with new technological concepts. The specific research objectives included: 1) identifying the requirements from the US Army for a spectator interface during virtual experiments, and 2) designing and developing a virtual spectator system within a video game environment to address spectator requirements. We then present a virtual experimentation case study we conducted on studying human-robot teaming during a security scenario to demonstrate the usage and usefulness of the developed virtual spectator system.

2. US ARMY REQUIREMENTS FOR A SPECTATOR INTERFACE

In the first phase of our research, we interviewed experts involved with the immersive simulation group at the Ground Vehicle Systems Center (GVSC) to identify the needs and requirements of a virtual spectator system to support virtual experimentation for soldier evaluation of technologies in gaming environments. These interviews and discussions were conducted over the course of the one-year project with a variety of stakeholders including software leads, data analysts, engineers, researchers, branch chiefs, technical experts, program managers, and chief scientists. These interviews and discussions were used to inform and iterate on the design as well as development of the virtual spectator system.

The interviews focused on questions pertaining to 1) how virtual experiments are currently spectated, 2) what type of camera perspectives are used during spectating, 3) what type of data is being acquired during these virtual experiments, and 4) how data is interpreted during experimentation or post-experimentation. The primary themes that arose when discussing spectator needs during a virtual experiment included the contexts when spectating a virtual experiment, types of spectators, reasons for spectating, challenges faced while spectating, and desired tools for a spectator interface.

2.1. Spectating Context

The virtual experiment spectating context consists of battlefield simulations with 80-120 soldiers simultaneously competing against each other, as opposing forces, to accomplish mission objectives within 8km-by-8km to 16km-by-16km environments (e.g., woodland, dessert, or artic). Within the experiments, soldiers are introduced to a variety of enabling technologies such as robots, manned/unmanned ground vehicles, unmanned aerial vehicles, and aided target recognition. Currently, the overall objective of these virtual experiments is to attain soldier feedback on these enabling technologies and can include feedback such as crew configurations, formations, vehicle capabilities, enabling capabilities, and networked capabilities.

2.2. Types of Spectators and Reasons for Spectating

Spectators of virtual experiments come from a variety of backgrounds including VIPs/Executives within the army (e.g., generals), engineers, and researchers. Individuals from these three backgrounds each have their own respective goals for spectating virtual experiments. VIPs and executives within the army are often spectating a simulated battlefield to gather insights or evaluate how the introduction of new enabling technologies influences overall mission objectives and/or soldier behaviors. Engineers are spectating virtual experiments to gather design requirements for their technologies and stress test technologies they have developed. This is done to analyze performance, reliability, integration issues, and deployment challenges with the technologies. Lastly, researchers spectate virtual experiments to investigate a variety of research questions (e.g., human factors, team dynamics) via hypothesis testing, exploratory data analysis, and identifying trends as well as patterns of behavior.

2.3. Current Challenges

Currently virtual experiments are spectated via a “God Mode” system which allows a spectator to independently free roam the environment and zoom in or zoom out. This approach poses numerous challenges for spectators including: 1) accessing data within the virtual environment, 2) visualizing this data, and 3) identifying where as well as when key events are occurring. Namely, current virtual experiments do not allow spectators to access or visualize data such as soldier positions, fire rates, vehicles states, or other pertinent data required for analysis. Instead, this information needs to be inferred by observing the visual events occurring in real-time. This is further complicated by spectators needing to identify where and when the most relevant events within a virtual experiment are occurring.

2.4. Desired Spectating Tools

A variety of spectating tools have been proposed during our interviews with members from GVSC. These have included: replay/playback systems; methods for annotating/flagging replays in the interactions; features to support rapid processing and visualization of gameplay data for different types of spectators;

approaches to automatically direct the spectator to view key events during a virtual experiment; and modularity to support different spectator interests.

3. VIRTUAL SPECTATOR SYSTEM

In the second phase, we designed and developed a virtual spectator system to address the needs and requirements gathered from the first phase of the project. The spectator interface consists of six main components: graphs, map layers, events, overlays, an automated camera director, and replays.

3.1. Graphs

During virtual experimentation, there is often a vast amount of data produced by data sources. The spectator interface has been developed to allow users to summarize data produced by a virtual experiment and depict relationships amongst different variables within the data. The interface provides support for spectators to produce graphs (e.g., boxplots, pie charts, and scatter plots) according to their desired needs and the data they are visualizing. These graphs enable spectators to choose the best representation for the data they are reviewing. An example of this would be a pie chart containing health percentage of actors out of the total health pool, Figure 1.

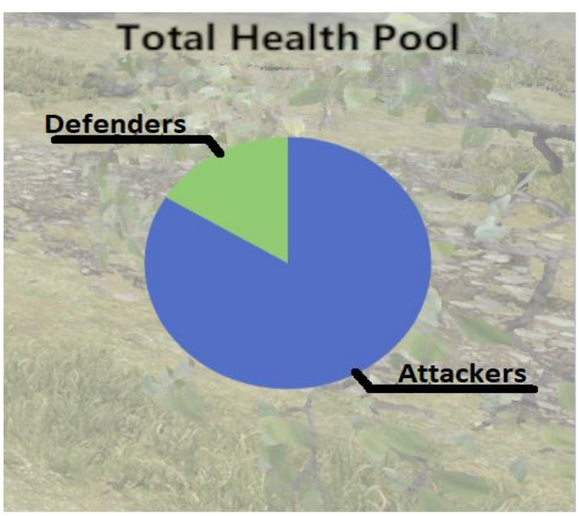


Figure 1: Pie chart visualizing total health percentage of actors on two opposing teams.

3.2. Map Layers

With many actors present, it can be difficult to keep track of individuals, and even more difficult to keep track of squads or higher hierarchical levels (e.g., platoons and companies). Map layers are translucent layers overlayed on top of the map of the virtual experiment to enable a spectator to spatially visualize patterns of behavior (e.g., movement patterns) of individuals, squads, and teams across a virtual experiment. Map Layers can contain data from all data sources. For example, a map layer could be a position heatmap visualizing regions traversed most frequently by actors, Figure 2. Stacking multiple map layers on top of each other also allows the spectator to gain a better understanding of how patterns in each layer affects and relates to other layers. For example, having a terrain stability layer on top of an actor position heatmap could show that certain areas have a high density of actors due to actors slowing down in areas of unstable terrain.

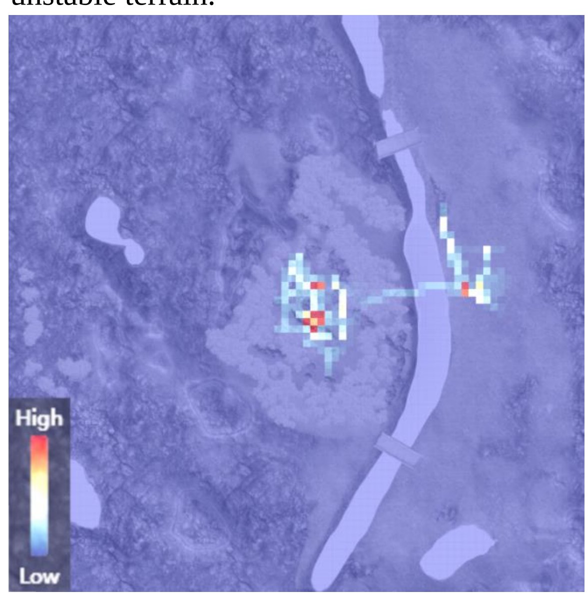


Figure 2: Heatmap showing movement patterns of actors over the course of a simulation. Red areas indicate high movement density and blue areas indicate low movement density.

3.3. Events

Events represent the results of interactions between actors in the virtual experiment and actions they are performing. In the spectator interface, we visualize events as a scrolling feed from newest to oldest, Figure 3(a). The location of the events can also be depicted as a map layer, Figure 3(b). This allows the spectator to track important events as they are happening while being aware of both their order of occurrence and their location. Events are mainly triggered from interaction data, but they may also be triggered by any type of action. An example of this is a robot deploying a bridge across a river.

(a) **(b)**

Figure 3: Event system visualizing actor interactions. **(a)** A scrolling events feed visualizes the events in chronological order from oldest at the bottom to newest at the top. **(b)** An events map layer visualizes the location of events that have occurred.

3.4. Overlays

As the virtual experiment is happening in 3D space, certain data that varies along the three spatial dimensions can be difficult to understand from a 2D interface. Overlays are interface elements that are superimposed over the 3D space of the virtual experiment as opposed to being static 2D elements. Unlike Map Layers, overlays offer a better sense of proportions of the data being represented and transparency of an actor's actions. For example, splines applied on the terrain can indicate the path taken by an AI, Figure 4. This allows the spectator to better orient themselves to the scale of the virtual environment and understand the actions of its actors.

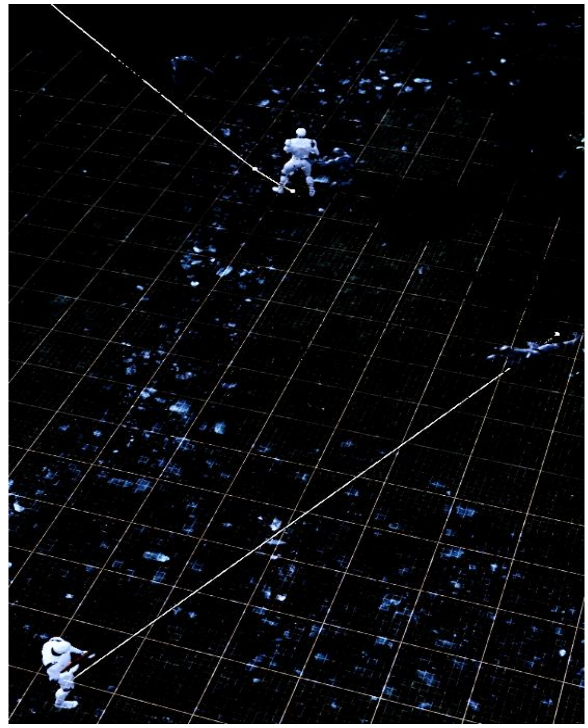


Figure 4: White splines visualizing the path planned by the AI actors.

3.5. Automated Camera Director

Due to the number of actors and size of the environment, virtual experiments can have a variety of events occurring simultaneously and it can be difficult for a spectator to find the most important events taking place during the experiment. The Automated Camera Director (ACD) automatically identifies as well as navigates the spectator camera towards the most interesting point in the simulation at any given time, this can be a region or a specific actor. It has two key components: 1) a camera interest function that takes in generated data and calculates an interest value for each actor or location; and 2) a camera position function that takes in the highest interest value calculated by the camera interest function and determines the best position for the camera to view that actor or location. This enables the spectator to be automatically directed to the most important events occurring within the virtual experiment at any given time.

3.6. Replays

Virtual experiments produce a large quantity of data that can be explored as well as evaluated from a variety of perspectives by different stakeholders such as quantitative data analysis by researchers and engineers or qualitative evaluations during after action reviews. To support such post-experiment data analysis, we have developed a replay component that enables a spectator to review historic experiments within a video player and annotate relevant events within the replay, Figure 5. This enables spectators to easily review virtual experiments and share insights amongst other stakeholders.

Figure 5: Replay system controls, showing play/pause, forwards and backwards skipping, and restart capability.

4. CASE STUDY: STUDYING HUMAN-ROBOT TEAMING

We present a virtual experimentation case study we conducted on studying human-robot teaming during a security scenario to demonstrate and provide guidance on the usage of the developed virtual spectator system. The study focused on evaluating the difference in user performance, behavior, trust in robots, and situational awareness between a human-robot teaming study conducted in a virtual environment and one conducted in the real-world.

4.1. Human-Robot Teaming Scenario

We have developed a human-robot teaming security scenario that consists of a human-robot team protecting vital assets within a facility. The objective for the human-robot team is to minimize the amount of time that vital assets are compromised by intruders.

In this scenario, a human security guard collaborates with two mobile robots to prevent two assets within the facility from being compromised by intruders. The facility is 170m x 330m in size with two buildings connected by a walkway. Building A is 90m x 170m in size with a single floor. Building B is 110m x 110m in size with two floors connected by a stairwell. Each building contains one asset in a secured room and the room is patrolled by a mobile robot. Building A also contains a monitoring room where a security guard can monitor robot camera feeds. Presented in Figure 6 is the layout of the facilities.

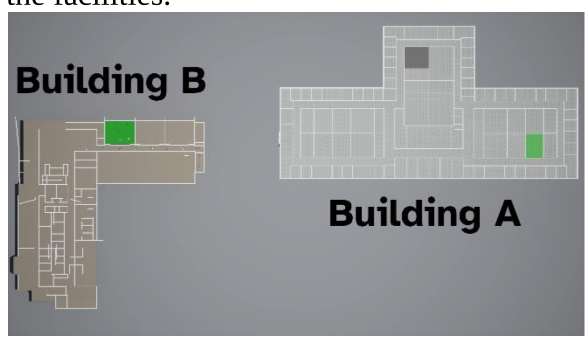


Figure 6: Layout of the facilities in the human-robot teaming scenario. Green squares indicate asset and robot locations. The dark gray square is the location of the monitoring room.

The robots can patrol the two rooms containing the assets and detect intruders so that a security guard can be informed about potential threats to the assets. Both the human and robots have limitations which require that they coordinate amongst each other to accomplish the overall objective of defending the assets. Namely, the human is unable to monitor all locations containing the assets simultaneously and the robots are unable to prevent intruders from compromising the asset. The human can interact with the robot in two ways: 1) use the monitoring room in building A to observe the cameras of the robots as they autonomously patrol the environment, or 2) receive text messages from the robots on a smartphone regarding potential intrusions which can enable the human to patrol other areas closer to the vital assets as well as help them plan their next step while securing another asset.

During the entire scenario, intruders are aiming to avoid being detected by the security team so they can compromise the assets in the facility. An asset is considered compromised when the intruder is physically situated near the asset for more than 60 continuous seconds. An asset can only be protected if the human guard physically encounters the intruder prior to the 60 seconds and anytime over 60 seconds is considered the amount of time the assets have been compromised (e.g., an intruder being around an asset for 68 seconds means the asset has been compromised for 8 seconds). Once an asset is compromised, the security guard must recover the asset by being physically present around the asset for 30 seconds if the asset has been compromised, or 15 seconds if the intruder was interrupted.

.

4.2. Study Design

We conducted a 2x1 between subjects design where participants underwent the human-robot teaming scenario either in the virtual world or physical world. Participants were randomly assigned to each condition. We aimed to make the virtual and physical versions of the experiment as similar as possible. This included having the same size and structure of maps, walking speeds, interaction capabilities with the robot and environment, and visual qualities of the environment. Presented in Figure 7 is a side-by-side comparison of the virtual and physical world conditions.

4.3. Participants

We recruited a total of ten participants ranging in age from 20-41 (μ=26.0, σ=7.071). There were five females and five males. Nine out of the ten participants had prior experience with robots, four of which had regular (daily or weekly) experience. All participants who had experience with robots also had experience controlling robots. Most participants had experience controlling robots via computer programming (seven out of nine).

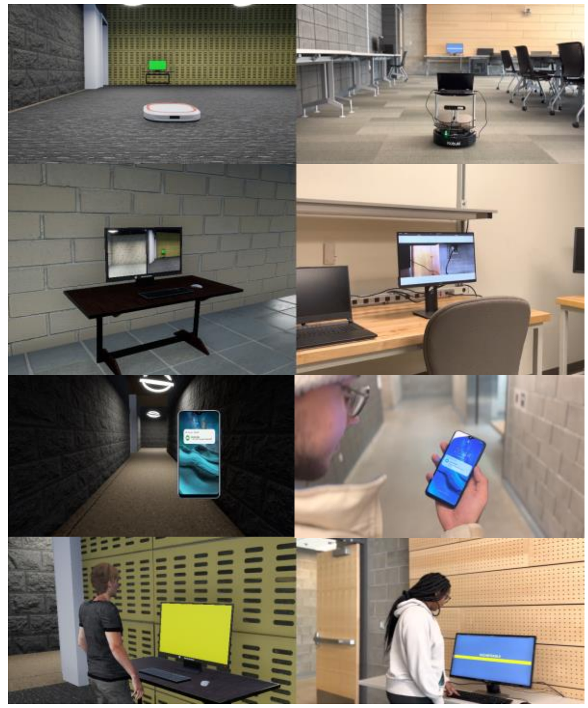


Figure 7: Side-by-side comparison of the virtual and physical world versions of the human-robot teaming scenario

4.4. Study Procedures

Participants were randomly assigned to either the virtual or physical world conditions. A researcher then explained the security task they would be performing with a human-robot team, provided a map of the facility along with locations of all relevant rooms (i.e., assets, robots, and monitoring room), and explained how they could interact with the robots. After all the explanations, participants were given the opportunity to ask any questions they had, explore the environment, and prepare for the task. Once the participants indicated they were ready to begin the human-robot teaming task session started. Each participant underwent two consecutive task sessions.

A task session followed the human-robot teaming scenario described in section 4.1. Over the two task sessions all participants experienced one session with one intruder and one session with two intruders attempting to comprise the assets. After each task session participants were then administered a questionnaire investigating their situational awareness using the Situational Awareness Rating Technique (SART) [5] and trust towards robots using the Trust-Perception Scale-HRI [6]. All virtual condition sessions were recorded using our virtual spectator system described in section 3.3 and all physical condition sessions were recorded with a chest mounted camera on the participant as well as cameras located in the monitoring room of the facility.

4.5. Measures and Metrics

To investigate the differences between a human-robot teaming study conducted in a virtual experiment or the real-world we measured user performance, behavior, trust in robots, and situational awareness within these two conditions.

Performance – We measured participant's performance in the task by measuring the percentage of time during the entire task that they kept the assets from being compromised.

Behavior – We measured participant behavior during the tasks by having a researcher review participant's movement patterns using heatmaps within the virtual spectator system we developed. To review task sessions conducted in the physical world in the virtual spectator system, we had a researcher replay the participants' runs in the virtual condition and record the data so that it could be reviewed in the virtual spectator system. We then manually identified common movement patterns and strategies amongst the participants during different phases in the security task (e.g., waiting for an intrusion or preventing an intrusion).

Trust in Robots – We measured participant's trust in robots using the Trust-Perception Scale-HRI. The Human-Trust Scale consists of 40 items measuring human, robot, and
environmental elements that affect trust (e.g., "What percentage of the time will robots be responsible?"). Participants were asked to respond to each item using a scale that ranged from 0-100% in intervals of 10%. The final mean score across the items was then used to provide an overall score on participant's trust toward robots.

Situational Awareness – We measured participant's perceptions of their own situational awareness during the task using Situational Awareness Rating Technique (SART). SART uses 9 items on a 7-point Likert scale that investigate three dimensions of participants' situational awareness: 1) demands on attentional resources, 2) supply of attentional resources, and 3) understanding of the situation. The final mean score of the 9 items was used to provide an overall score on participant's situational awareness during the task.

4.6. Results from Statistical Analysis

To investigate differences in human-robot teaming studies conducted in the physical and virtual worlds we applied two-tailed independent samples *t*-tests. In cases that the assumption of normality and sphericity were violated, we applied a Mann-Whitney U test.

Participants in the virtual world condition had higher performance with 91.35% as the average time that they were able to keep the assets secure while real world participants kept the assets secure only 88.85% of the time. However, there was no statistically significant difference between their performance in the two conditions ($t(8)$=-0.454, p=0.662).

Participants trust towards robots in the physical world condition was higher than that in the virtual world. Participants average trust scores in the physical world was 71% and participants average trust scores was 60.7% in the virtual world. However, there was no significant difference in trust between the physical and virtual world conditions (U=11, p=0.754)

Participants had higher situational awareness in the virtual world condition than in the physical world with virtual world participants scoring on average 19.4 on the SART scale and physical world participants scoring on average 15.6. There were also no significant differences in situational awareness in the virtual and physical conditions for situational awareness ($t(8)$=-0.64, p=0.54).

4.7. Results from Virtual Spectator System

Utilizing the virtual spectator interface on the data we collected from our pilot study, we identified common behavioral patterns that occurred in the virtual world and physical world conditions.

The first column of heatmaps in Figure 8(a) show a movement pattern that only occurred in the physical world. Participants walked outside, which was likely due to there being less natural constraints perceived by the participants in the physical world whereas in the virtual world all the participants moved directly between the two buildings because they naturally interpreted this was the only means of entry.

The second column of heatmaps in Figure 8(b) demonstrates that different strategies were used by top participants in the physical world condition and virtual world conditions. Namely, many physical world participants chose to place themselves in between the two rooms containing the assets in the facility. While those who participated in the virtual world chose to stay in one of the asset rooms and only left to the other room when there was an intrusion. This is likely due to them expecting that it would not take very long to walk between the two rooms as they themselves did not need to exert any physical energy.

Lastly, in Figure 8(c) we also observed that the virtual world participants had lower spatial awareness than their physical world counterparts. Many participants had this movement pattern where they circled around a room because they had gotten lost. This is likely due to a lack of proprioception which caused participants to have reduced spatial awareness of their surroundings. Furthermore, the walls of the virtual environment often had a consistent visual pattern which was not present in the physical world.

4.8. Discussion

Overall, the results from our case study suggests that human-robot teaming tasks conducted in the virtual and physical world produced quantitatively similar results in performance, perceptions of situational awareness, and perceptions of trust towards a robot. However, upon further inspection of participant behaviors during the tasks using our virtual spectator system we found that participant strategic behaviors and movement patterns differ greatly in the virtual world in comparison to the physical world. These differences are likely due to differences in natural constraints and visual qualities in the environment, physical energy expenditure, and proprioception.

5. CONCLUSION

In this paper, we present the design and development of a virtual spectator system that is tailored towards US Army virtual experimentation needs through feedback and discussions with GVSC. A case study was conducted to demonstrate the usage and utility of the system. Namely, a user study involving a human-robot teaming security scenario was conducted to investigate differences in user performance, behavior, trust, and situational awareness in the physical and virtual world. Statistical analyses of our results did not reveal any significant difference between users' performance, trust, and situational awareness in the human-robot teaming scenario in the physical and the virtual world. Relying only on this analysis would have led us to naively conclude that human-robot teaming studies conducted in the virtual and physical world produce comparable results. However, with the virtual spectator system, we were able to closely review participant behavioral patterns and uncover valuable insights that were overlooked from our statistical analysis. This demonstrates the utility of our virtual spectator system as an additional tool for supporting the analysis of virtual experiments.

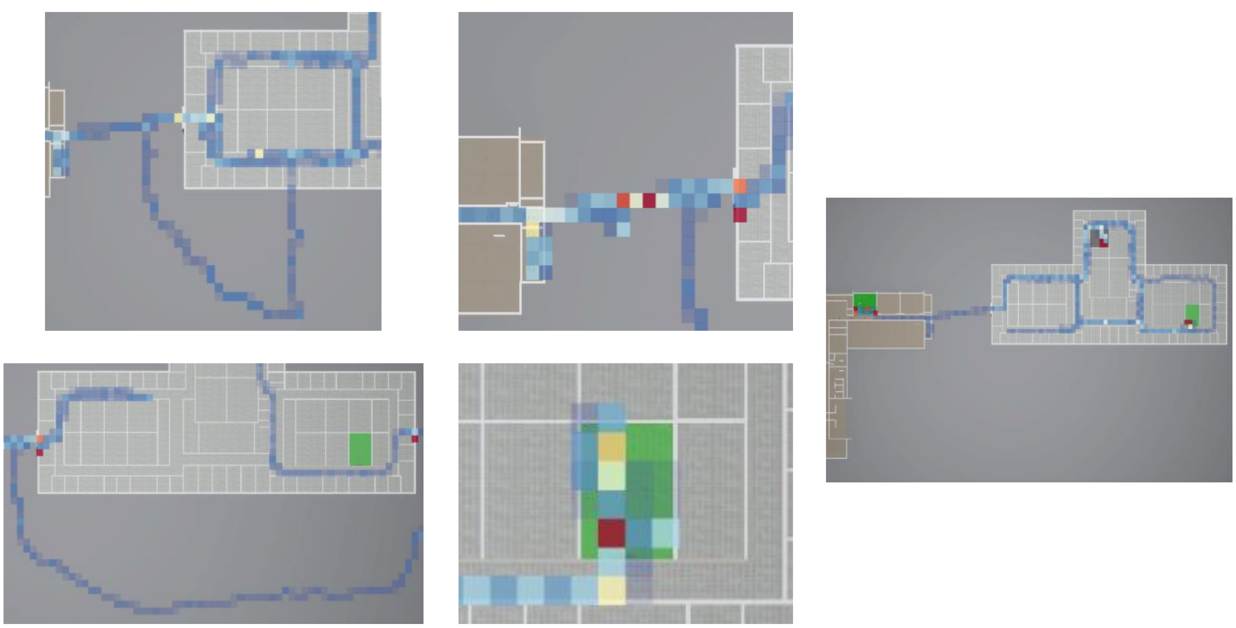
6. REFERENCES

[1]D. J. Gorsich, "The Use of Gaming Engines for Design Requirements," in Proceedings of the Design Society: DESIGN Conference, 2020, pp. 141–146.

[2]GVSC Public Affairs, "3rd virtual experiment informs future manned-unmanned teaming missions," 2019. [Online]. Available: https://www.army.mil/article/228078/3rd_virtual_experiment_informs_future_manned_unmanned_teaming_missions. [Accessed: 11-Feb-2021].

[3]T. Y. Qian et al., "It is in the game: dimensions of esports online spectator motivation and development of a scale," European Sport Management Quarterly, vol. 20, no. 4, pp. 458–479, 2020.

[4] J. W. Creswell, Research Design: Qualitative, Quantitiative, and Mixed Methods Approaches, 3rd ed. Los Angeles: Sage Publications, 2009.



(a) (b) (c)

Figure 8: Behavioral patterns identified using the virtual spectator system. **(a)** Heatmaps of physical world participants walking outside of the buildings because they perceive different environmental constraints. **(b)** Heatmaps of different strategies used by physical world participants (top) and virtual world participants (bottom) due to differences in physical energy expenditure. **(c)** Heatmap of participants getting lost due to lack of proprioception and situational awareness.

[5] R. M. Taylor, “Situational Awareness Rating Technique (SART): The development of a tool for aircrew systems design,” Situational Awareness, pp. 111–128, 2017.

[6] K. E. Schaefer, “The perception and measurement of human-robot trust,” Ph.D. dissertation, Dept. of Modeling and Simulation, University of Central Florida, Florida, 2013, p. 359.